

CARNEGIE INSTITUTION OF WASHINGTON

NASA Contract NSR 09-140-001

Modernization of the 60-inch Telescope at the Mount Wilson Observatory

Final Report

December 1973

1. History of Original Contract and Follow-up Work.

A contract for modernization of the Mount Wilson 60-inch telescope was awarded by NASA to the Carnegie Institution July 1, 1966. Under this contract, the original hour angle and declination drives were replaced, digital coordinate readouts were added, a Cassegrain/coudé flip cage was built and installed, the telescope was completely rewired, a new control console was installed, and a coudé spectrograph was completed. Under support from the Carnegie Institution, extensive building modifications also were made to provide a working floor at mezzanine level for a computer and a coudé observing room. These modifications and additions were completed by February 1970, and the telescope returned to regular and continuous use for stellar and planetary astronomy. Details of the work are contained in fourteen quarterly reports to NASA extending from August 1966 to February 1970.

More recently, after extensive engineering study, a decision was made to replace the original declination bearings, which had become hopelessly worn in more than sixty years of service. The required machine work and installation of new spherical roller bearings was completed in December 1973. This resulted in decreased declination gear runouts, backlash, and bearing friction in all telescope positions by a factor of ten or more. Thus for the first time the performance of the declination drive has now been optimized.

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2. Contract Amendment for Completion of Data System.

A general-purpose computer-controlled data system was conceived and partially assembled as part of the modernization program under the original NASA contract, but was deferred by our decision when it was found that the completion cost would overrun the original budget. A supplementary budget (\$60,000) for completion of this system was awarded by NASA to the Carnegie Institution July 1, 1971. The system has now been completed, together with the installation of all required cabling, and is operational in the 60-inch dome.

The configuration of the system is the same as other computer installations at the Hale Observatories as described by E. W. Dennison (*Pub. Astron. Soc. Pac.*, 84, 190, 1972, copy attached). A common software library is shared by these systems. In the case of the Mount Wilson 60-inch telescope, the computer has access to the coordinate readouts and controls the tracking rates but does not otherwise interact with control of the telescope, dome, or windscreen. Also, the system does not include a magnetic tape unit although one is likely to be added in the future. These features were deleted partly for the purpose of holding down costs. A mobile observer's terminal desk, on which all observing station computer controls and displays are permanently mounted, was added to the 60-inch system to considerably improve the convenience of setups and operation. The regular maintenance of this system, together with a similar computer system in the solar telescope and all other Mount Wilson electronics, is the responsibility of a C.I.W.-employed electronics specialist who is resident on the mountain.

3. Photographs.

Photographs illustrating many of the modifications and new installations performed under or in conjunction with the modernization contract will be forwarded at a later date.

4. Research Applications.

The telescope has been used, almost continuously, in a variety of research applications since the completion of the first phase of the modernization program in 1970. One of its first uses in this period was a thesis project entitled "Infrared Emission from Asteroids at Wavelengths of 8.5, 10.5, and 11.5  $\mu\text{m}$ " by Dr. Dennis Matson. In this project, rapid and accurate coordinate readout capability (afforded for the first time by the new digital readout system) was essential in locating asteroids too faint to be seen easily by visual means. More recently (1972-73) Matson and others have pursued further spectrophotometry of asteroids in the visual and near IR (0.3 - 2.5  $\mu\text{m}$ ) wavelengths using the 60-inch telescope, partly in collaboration with the Caltech infrared group.

In other recent applications (1972-73), Dr. T. McCord of MIT employed the telescope with the MIT silicon vidicon system to record images of Jupiter, Saturn, and Uranus through narrow band interference filters in methane and ammonia bands; Dr. D. G. Currie and students from the University of Maryland used a newly-developed amplitude interferometer at the Cassegrain focus to conduct observations of the apparent angular size and structure of late-type giant stars; Dr. P. H. Richter of California State University, Northridge, obtained observations of Jupiter

and Ganymede with an image tube for the purpose of studying ways of improving the image resolution by digital processing; Drs. R. W. Shorthill and T. F. Greene pursued photometric observations of Jupiter and the Galilean satellites during an ingress and egress of Callisto in late 1972.

The telescope has been applied extensively, with its Cassegrain spectrum scanner or various infrared photometric devices, for the measurement of energy distributions in planets, asteroids, stars, gaseous nebulae, and galaxies. It is anticipated that observations of this type, typically involving the recording of large quantities of data, will be significantly aided by the computer system recently placed into operation at the telescope. However, more experience must be acquired with this system before a full assessment can be given.

An effort is currently underway, in collaboration with the Caltech infrared group, to provide additional facilities at the 60-inch specifically designed for infrared work (for which the observing conditions at Mount Wilson and its proximity to Pasadena are in many ways ideally suited). Also in prospect is the initiation of an extensive study of stellar chromospheres for the purpose of investigating analogues of the solar cycle. For this purpose we expect to build a spectrometer for which funds are being requested from NSF by A. H. Vaughan, G. W. Preston, and O. C. Wilson. This instrument would be interfaced to the computer data system at the 60-inch telescope.

## THE HALE OBSERVATORIES' COMPUTER SYSTEM\*

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The telescope computer systems which will be described here have been developed for operation on the telescopes of the Hale Observatories. As of this time the hardware has been completed and the software or computer programming is nearly complete, although none of the systems have been used for astronomical observations.

*Key words:* instrumentation — computer control system

### System Development

When this project was started approximately three years ago, we attempted to design a computer system which would have all of the advantages of the older hard-wired data systems plus the advantages which are obtainable with a computer. Our initial concept was to develop a system which centered around a relatively inexpensive minicomputer which was capable of handling a large number of custom made peripheral devices designed to serve the specific needs of astronomical observers. We wanted to have a system which would be able to control the telescope and all of its various functions as well as collecting, displaying, and recording observational data. The design had to provide the observer and the night assistant with adequately flexible controls over the entire system. Still another criterion, which we felt was important, was that our system should be capable of having new peripheral devices added without disturbing any of the previously constructed hardware. With the older hard-wired data systems, we had encountered the problem that when a new device was added the data system had to be taken out of operation. After the old circuits were modified or removed and the new circuits added and thoroughly debugged, the system could again become operational. With the philosophy of our new computer systems we wanted to be able to add new peripheral hardware devices by connecting them with new plugs and cables. These devices could be tested with-

out disturbing any of the older hardware. In addition, if one of these new devices did not function correctly, it could be removed for further testing without any disruption of the system operation. With each new hardware device, new computer software drivers would be necessary; but here also the development of the new software would not disturb the previously functioning software. This means that the checkout and debugging operations of a new system could be accomplished during the daytime, and, each evening the system could be returned to its older configuration for the night's operation.

The block diagram for the system which we finally developed is shown in Figure 1. The heart of the system is a Raytheon 703 computer with 16,000 words of core memory, a standard ASR 33 teletype printer with a paper tape punch and reader, a 9-track magnetic tape recorder, and a strip printer. The computer communicates with the other peripheral devices by means of a universal input/output controller.

### Data System

Because accurate civil and sidereal times are fundamental to both data acquisition and telescope control, we developed a digital clock which is accurate to 1 part in  $10^8$  and can be set to an accuracy of 0.1 second of time for both civil and sidereal times. Because of the fundamental importance of this unit, it has a separate display which is independent of the computer.

At the present time photometric data are collected in a dual pulse-counter unit which is connected to a chopper-time unit for use with mechanical or electronic star/sky choppers. One

\*Paper presented at the symposium "Advanced Electronic Systems for Astronomy — 1971," Santa Cruz, 31 August–2 September 1971.

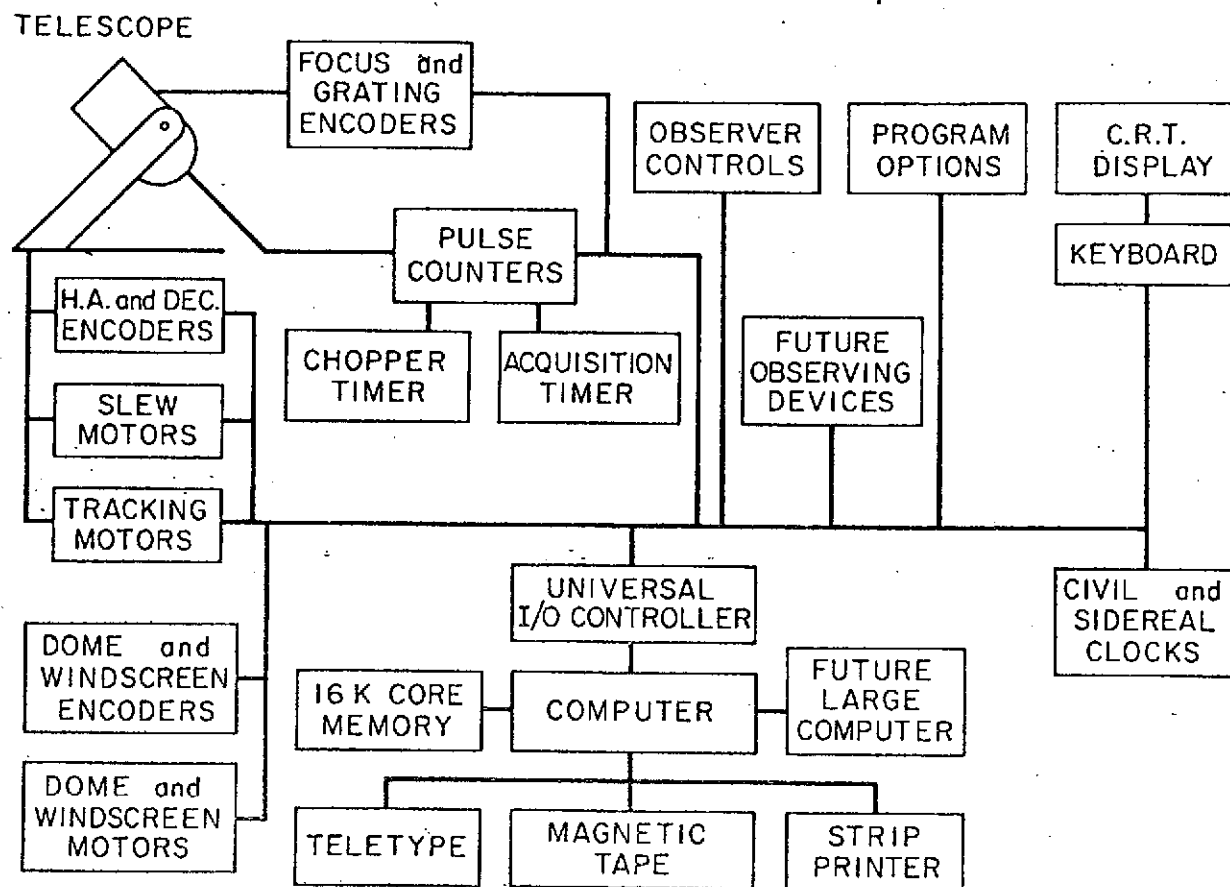


FIG. 1—Block diagram for a typical Hale Observatories' computer system with provisions for data collection and telescope control.

of these counters can be used as a preset counter. This unit also contains an acquisition timer to determine the length of time required to make a specific observation. All of these devices are addressable and controllable by the computer.

The observer communicates with the system by means of three units: the first is an observer control box which enables him to control the data-gathering cycle; the second unit provides the observer or night assistant with the option of choosing various program functions which have been built into the software system (this is similar to a computer sense switch control); the third unit consists of a Cathode Ray Tube (CRT) display and keyboard. The CRT character generator unit has a composite video signal output which can be displayed on a standard television monitor. All of the data, which are important to the observational process, are displayed on this unit both to the night assistant and the observer at the telescope. The keyboard

unit is used to enter fixed data into the computer system and also to control various computer functions such as the acquisition time, preset counter, telescope tracking rates, etc. By using these units to control the system, it is not necessary for the night assistant or the observer to manipulate the computer directly. This ensures that the basic computer program will not be disturbed accidentally and also that the computer can check for inconsistent or erroneous operational commands.

Absolute position digital encoders are used to read out the position of the secondary-focus mirror, the grating of spectrum scanners, the hour angle, and the declination of the telescope. Other peripheral devices control the slewing, tracking, and instrument stepping motors. The dome and windscreen positions are also encoded and the computer controls the dome and windscreen motor drives.

The most important element in the entire

system is the universal input/output controller. This device can be connected by means of a multiconductor serial cable to 250 different devices. Each device has its own designation and can be addressed by the computer. Once addressed by the computer, it can be issued up to 256 different commands. In turn each device has the possibility of generating an interrupt signal which informs the computer that data are ready to be transmitted by that particular device. The availability and status of each device can be sensed by the computer. All data to and from the devices are transmitted 8 bits or one byte at a time.

For a typical observing operation, the observer or the night assistant will select the program options which are applicable to that particular observation, and then by means of a keyboard enter into the computer the various pertinent adjustable parameters, such as, the acquisition time for a pulse-counting photometric observation and the name of the object. When the observer centers on the star which he wishes to measure, he presses a button on the control console which starts the counters into operation. After the acquisition timer has reached its predetermined value, the data counters are shut off and the computer is informed by means of the interrupt circuit. The next step is for the computer to interrogate all of the various encoders, clocks, and other devices and gather the data into an output buffer. The computer then starts the strip printer and magnetic tape recorder to permanently record the data. The strip printer serves not only as a redundant data channel but also as a convenient means by which the observer can review the data which were collected earlier during the observing period.

While the data-collection process is in operation, the computer periodically refreshes the image on the CRT display with the most recent clock and encoder information. The computer also interrogates the dome and windscreen encoders and compares their positions with those calculated from the telescope coordinates. If needed, the computer operates the dome and windscreen motors. The tracking rates for the telescope are also automatically computed from the telescope's coordinates and sent to the tracking rate generator.

### Software System

Although the computer was supplied with an excellent software library by the manufacturer, a large amount of effort has been invested to generate the program for this system. The uniqueness of the program comes from the special and exacting requirements of astronomical observations and the fact that most of the program is concerned with special input and output devices. The program contains approximately 70 subroutines. Of these, 11 are supervisory subroutines which link and control the other subroutines. There are 35 input or output subroutines which control the data to and from the various peripheral devices, such as the TV display, the strip printer, the clocks, the counters and timers, etc. Ten arithmetic subroutines are required. The remaining 14 subroutines are required for code conversion, such as binary to binary coded decimal, TV character generator code to binary, binary to strip printer, etc., and format preparation for the various displays and output devices. Fortran language is used for the part of the program which computes the hour-angle and declination-tracking rates, the refraction displacements, the dome and windscreen positions, and the air mass. We anticipate that the system program will continue to be enlarged and revised as new observing requirements develop in the future.

### Telescope Control Systems

Because modern solid-state relays offer many advantages over mechanical relays, we are in the process of installing an all solid-state control system in the 150-foot tower at Mount Wilson. The principal advantage of these systems is that modern solid-state component reliability is approaching the point of  $5 \times 10^{-8}$  failures per component per hour of operation at a 90% confidence level. This means that with a system of 1000 components, one would expect one failure for the system every 20,000 hours of operation. Thus, a system which is used 2000 hours per year would be expected to have one failure every 10 years. If a control system with this reliability can be achieved in fact, it will be a great asset to any telescope. A second advantage, which is even greater for modern telescopes using large amounts of electronics, is that

the solid-state relays turn on at a time of zero line voltage and turn off at the instant of zero current. This means that there are no switching transients generated by the power line control elements. A third advantage is that the control logic, which is used for such a system, is far more flexible because the operational functions are not limited by the available number of contacts per relay. Finally, these components are more easily controlled by computer circuits. One of the disadvantages of such a system is that the failure mode is unpredictable and, therefore, we are installing extra sets of safety switches on the controlled devices to insure that any possible failure will not result in mechanical damage. Many large telescopes already have such extra safety switches in order to insure against the large losses which would result in cases of control-system malfunction.

When a device which is being controlled requires a simple on/off action, the circuit is relatively straight forward, but when controlling large DC motors, the circuits become more complex. We have developed a circuit which will start the motor with a low-armature current and then advance the current through 8 or 16 steps to full current. If a proportional type control is required or if the motor is required to operate at less than full torque, the computer can achieve this by appropriate instructions.

We have designed a number of stepping motor circuits with varying degrees of sophistication. The most complex design, so far, is one which allows the computer to specify the stepping motor speed up to 2000 steps per second and the total number of steps required as well as the direction of the motor.

For tracking motors we have used a synchronous motor for the hour angle and a stepping motor for declination. Both of these motors are driven by a computer-controllable preset counter working from our standard 5 MHz crystal oscillator. Once the computer has set the preset counter value, the output rate remains constant until a new instruction is issued by the computer. We have made provision for manual control of the rate generator for special operations or computer failure.

#### Summary

We have been developing a comprehensive data and control system which is based on a small computer. We have also developed all solid state control techniques. Most of these devices are now going into operation and we can report that we see no major difficulties, and there is every reason to believe that these techniques will result in very substantial increases in astronomical observing effectiveness.